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During this grant, the 2048x2048 Tektronix CCD detector was installed and put into operation on the Spacewatch Telescope at Kitt Peak in Arizona. The CCD was installed inits dewar during the fall of 1988 and tested in January 1989. Scanning for near-Earth asteroids was started in the visual mode awaiting the arrival of the computer system. The first near-Earth asteroid was discovered in the fall of 1989. The Solbourne-Sun computer system was installed and a major effort involved the programming for the computerized discovery of moving objects. The computerized discovery of moving objects was operational in September 1990 and led to the discovery of the asteroid 1990ss. Work has involved the discovery of objects, verification of heliocentric orbit and astrometric determination of orbital parameters. Improvement was made in the observing programs, hardware and software. Refinements were made in the installation of the Guide Star Catalog of the Hubble Space Telescope. Positions can now be determined in real time with an accuracy of about 0.4 arcseconds.

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FINAL TECHNICAL REPORT
AFOSR-89-0027
1 November 1988 - 31 October 1991

These are the years of installation and putting into operation of the 2048 x 2048 Tektronix CCD on the Spacewatch Telescope. We had waited 3-1/2 years for the delivery of that CCD and in these years prepared and exercised our CCD-scanning software with the 320 x 512 RCA CCD. The new one was delivered just about at the time of the start of AFOSR-89-0027 and this grant is largely responsible for the installation and, indeed, the success of this surveillance system.

The CCD was installed in its dewar during the fall of 1988, and first tested on the telescope in January 1989. By April 1989 we were scanning for near-Earth asteroids but only in a visual mode, as the computer system of our DURIP grant, also monitored through AFOSR, had not as yet arrived. However, we did do our best that spring at the telescope and gained valuable experience with the software for CCD scanning, which was already extensive.

In the fall of 1989, Dr. David Rabinowitz came on board and he discovered, with Mr. J. Scotti, our first near-Earth asteroid, 1989UP, still in the visual mode. Most of that second year of AFOSR-89-0027 was spent on the installation of the DURIP computer, which is a Solbourne-Sun system, and on programming it for the computerized discovery of moving objects. It sounds easy to summarize in so few words so much work; in the end, about ten manyears of computer programming had been invested in this system.

The computerized discovery of moving objects came into full swing in September of 1990 with the discovery of 1990SS. During the remainder of the third year of AFOSR-89-0027 we had our hands full with discoveries of interesting objects, verification that they were real objects in heliocentric orbit and not in geocentric orbit, and the astrometric followup

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so as to make firm their orbital parameters. There was further improvement in the observing programs, the hardware and software, and refinements of the 2048 Sun system. Much of this was accomplished during the summer of 1991 when we took the system out of operation for two months during monsoon time. Refinements were made particularly in the installation of the Guide Star Catalog of the Hubble Space Telescope. By September 1991 this was in operation, and the positions are now coming out in real time with a precision of about ± 0.4 arcsecs.

The two discovery tables attached to this Report illustrate the work accomplished in these three years. The following papers were published or prepared in the time of this Report. In conclusion, we thank AFOSR for its continued support of our Spacewatch work.

"Drift Scanning with a TK2048 CCD," T. Gehrels, R. S. McMillan, J. V. Scotti, and M. L. Perry, *Astron. Soc. of Pac. Conf. Ser.*, 8, "CCD's in Astronomy," ed. G. H. Jacoby (Provo: Brigham Young Univ. Press), 51-52, 1990.

"Scanning with Charge-Coupled Devices," T. Gehrels, *Space Science Reviews*, 58, 347-375, 1991.

"Detection of Earth-Approaching Asteroids in Near Real Time," D. L. Rabinowitz, *Astron. J.*, 101, 1518-1559, 1991.

"Near Real-Time Detection of Earth-Approaching Asteroids," D. L. Rabinowitz, J. V. Scotti, M. L. Perry, T. Gehrels, and R. S. McMillan, *B.A.A.S.* 22, 117, 1990.

"Near Miss of the Earth by a Small Asteroid," J. V. Scotti, D. L. Rabinowitz, and B. G. Marsden, *Nature*, 354, 287-289, 1991.

"The Size Distribution of the Earth-Approaching Asteroids," D. L. Rabinowitz, 1992, in preparation for the Astrophysical Journal.

"The Flux of Small Asteroids Near the Earth," D. L. Rabinowitz, in *Asteroids, Comets, and Meteors IV*, edited by A. Harris and E. Bowell (Lunar & Planetary Inst., Houston), in press.

"Automated Detection of Asteroids in Real-Time with the Spacewatch Telescope," J. V. Scotti, T. Gehrels, D. L. Rabinowitz, in *Asteroids,*

Comets, and Meteors IV, edited by A. Harris and E. Bowell (Lunar & Planetary Inst., Houston), in press.

"On the Search for Near-Earth Asteroids," J. Drummond, D. Rabinowitz, and M. Hoffmann, in Resources of Near-Earth Space, edited by J. S. Lewis and M. S. Matthews (Univ. of Ariz., Tucson) in press.

There have been many writeups in the *New York Times* and other papers in the U.S. and abroad regarding our discoveries of 1991BA and 1991VG.

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Spacewatch Discoveries, First Year

Identification	Perihelion distance (AU)	Aphelion distance (AU)	Incli. nation (deg)	dia- meter (km)	Date of Discovery	Remarks
1989 UP	0.98	2.7	3.9	0.3	27 Oct.,1989	elongated; perihelion at Earth orbit
1990 3S	0.89	2.5	19.4	0.9	25 Sep.,1990	
1990 TG1	0.77	4.2	9.1	4.6	14 Oct.,1990	Discovered at 2.9 AU from Sun
1990 UN	0.81	2.6	3.7	0.09	22 Oct.,1990	H-23.5
1990 UO	0.30	2.2	29.3	0.4	22 Oct.,1990	perihelion at Mercury orbit
1990 UP	1.10	1.5	28.1	0.4	24 Oct.,1990	Amor; slow rotation
1990 VA	0.71	1.3	14.2	0.6	9 Nov.,1990	Aten; perihelion at Venus orbit
1991 AM	0.51	2.8	29.7	2.3	14 Jan.,1991	crosses Venus orbit
1991 BA	0.71	3.8	2.0	0.009	18 Jan.,1991	smallest object found so far
1991 BN	0.87	2.0	3.4	0.5	19 Jan.,1991	
1991 CB1	0.64	2.7	15.8	1.3	15 Feb.,1991	
1991 EE	0.84	3.6	9.8	1.5	13 Mar.,1991	
1991 FA	1.08	3.0	3.2	1.5	17 Mar.,1991	Amor
1991 FE	1.07	3.5	4.5	5.8	18 Mar.,1991	Amor
1991 JR	1.04	1.8	10.1	0.14	8 May, 1991	Amor
1991 LH	0.37	2.3	51.1	1.0	14 June,1991	

In addition to the discoveries, Spacewatch "rediscovered" 1990 UP (twice), (1865) Cerberus, P/Kopff, P/Taylor, P/Helin-Roman-Alu 2, and P/Hartley 1. Also, five objects were followed because of their apparent fast motion, but the eventual orbit indicated they were on the inside of the asteroid belt, and two were in geocentric orbit.

Spacewatch Discoveries, Second Year

Identification	Perihelion distance (AU)	Aphelion distance (AU)	Incli. nation (deg)	dia- meter (km)	Date of Discovery	Remarks
P/Spacewatch	1.58	4.5	9.5	-	10 Sep.,1991	
1991 RJ2	1.26	2.7	9.0	0.7	2 Oct.,1991	
1991 TT	1.00	1.4	14.8	0.03	6 Oct.,1991	
1991 TU	0.94	1.9	7.7	0.009	7 Oct.,1991	another small one
1991 VA	0.93	1.9	6.5	0.02	1 Nov.,1991	
1991 VG	0.97	1.1	1.6	0.008	6 Nov.,1991	smallest one so far*
1991 XA	0.98	3.6	5.3	0.009	3 Dec.,1991	
1992 AD	8.7	32.2	24.7	140	9 Jan.,1992	Chaos
1992 AE	1.24	3.2	6.4	3.3	10 Jan.,1992	Amor
1992 BA	1.25	1.4	10.5	0.4	27 Jan.,1992	
1992 DU	0.96	1.4	25.1	0.05	26 Feb.,1992	Apollo

*This may be an upper stage of a spacecraft, or, if natural, a new type of asteroid. In addition to the discoveries, Spacewatch rediscovered 3288 (an Apollo), 3122 (an Amor), P/Shoemaker-Levy 5, P/Gunn and (2060) Chiron (!). 1991 RJ2 had been discovered by Helin in September, but it was then lost. We also obtained preliminary orbits for objects that at first looked promising, namely 1 Trojan, 1 Hilda, 1 Flora, 5 Mars-Crossers and 3 Hungarias.